

# **Modal Mapping Techniques for Geoacoustic Inversion and Source Localization in Laterally Varying, Shallow-Water Environments**

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## **LONG-TERM GOALS**

The long-term goal of this research is to increase our understanding of shallow water acoustic propagation and its relationship to the three-dimensionally varying geoacoustic properties of the seabed.

## **OBJECTIVES**

The scientific objectives of this research are: (1) to develop high-resolution methods for characterizing the spatial and temporal behavior of the normal mode field in shallow water; (2) to use this characterization as input data to inversion techniques for inferring the acoustic properties of the shallow-water waveguide; and (3) to use this characterization to improve our ability to localize and track sources.

## **APPROACH**

An experimental technique is being developed for mapping the normal mode field and its wavenumber spectrum as a function of position in a complex, shallow-water waveguide environment whose acoustic properties vary in three spatial dimensions. By describing the spatially varying spectral content of the modal field, the method provides a direct measure of the propagation characteristics of the waveguide. The resulting modal maps can also be used as input data to inverse techniques for obtaining the laterally varying, acoustic properties of the waveguide. The experimental configuration consists of a moored, drifting, or towed source radiating one or more pure tones to a field of freely drifting buoys, each containing a hydrophone, GPS navigation, and radio telemetry, as shown in Fig. 1. A key component of this method is the establishment of a local differential GPS system between the ship and each buoy, thereby enabling the determination of the positions of the buoys relative to the ship with submeter accuracy. In this manner, the drifting buoys create 2-D synthetic aperture horizontal arrays along which the modal evolution of the waveguide can be observed in the spatial domain, or after beam forming, in the horizontal wavenumber domain. In this context, two-dimensional modal maps in range *and* azimuth, as well as three-dimensional bottom inversion in range, depth, *and* azimuth, become achievable goals. In addition, these high-resolution measurements have provided significant new insights into source localization and tracking techniques.

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## WORK COMPLETED

Prior to 2006, three successful Modal Mapping Experiments (MOMAX) were completed. Two of these experiments (MOMAX I and SWAT/MOMAX III) were conducted in the East Coast STRATAFORM/SWARM area off the New Jersey coast and one (LWAD 99-1/MOMAX II) was carried out in the Gulf of Mexico. In these experiments, several drifting MOMAX buoys received signals out to ranges of 20 km from moored, drifting, and towed sources transmitting pure tones in the frequency range 20-475 Hz. In the traditional MOMAX deployment, a source transmits a pure tone (usually several) of precisely known frequency to the MOMAX buoys. The known carrier frequency contribution to the total phase is removed from the measured signal, and the resulting pressure field magnitude and phase versus time data are then merged with the corresponding GPS-derived source-receiver positions versus time. This procedure enables the determination of the pressure magnitude and phase as a function of two-dimensional position. High-resolution beam-forming techniques (corresponding to the application of an asymptotic Hankel transform) and inverse methods are then applied to these synthetic aperture data to obtain the modal information and the geoacoustic properties of the seabed. On Aug. 30 – Sept. 5, 2006, MOMAX IV was successfully conducted as part of SW06, the ONR-sponsored, multi-institutional, multi-ship, series of shallow-water experiments that were conducted off the New Jersey coast throughout the summer of 2006. A wide range of environmental data was also obtained as part of SW06 that included an extensive suite of physical oceanographic measurements. As a result, a primary focus of SW06/MOMAX IV was the study of the effects of water column variability on the modal inversion process.

## RESULTS

SW06/MOMAX IV was conducted aboard the R/V Oceanus, which served as the source ship from which the NUWC J15-3 sound source was suspended from the A-frame at a depth of 60 m. The source transmitted pure tones for a period of approximately 25 hours with frequencies of 50, 75, 125, and 175 Hz. These signals were received by 4 drifting MOMAX buoys, as well as an 8-channel Webb vertical line array (VLA), with 8 m hydrophone spacing, that was deployed by the R/V Oceanus in the same area. The VLA was deployed on Aug. 31 and recovered on Sept. 8 on a subsequent R/V Oceanus cruise. The ship track, the trajectories of the drifting buoys, and the location of the VLA are shown in Fig. 2. Also shown are the positions of 3 environmental moorings and 3 acoustic sources that were already present in the area as part of the suite of SW06 experimental assets. This experimental site was chosen because of the proximity of these assets and the presence of subbottom river channels which introduce lateral variability into the bottom environment. These channels are of interest because one of the major goals of this work is to determine the relative effects of fluctuations in the water column (e.g., due to internal waves) versus lateral variation in the seabed on low-frequency modal propagation and geoacoustic inversion. In further pursuit of detailed water column information, both the VLA and the sound source string were outfitted with a series of temperature sensors. The temperature measurements obtained on the VLA and sound source string are shown in Figs. 3 and 4, respectively. In addition, each MOMAX buoy was equipped with two temperature sensors and one temperature/pressure sensor. It is clear from these measurements that the most dynamic portion of the water column lies in the thermocline region at 20-40 m depth, where internal wave effects are expected to be concentrated. The GPS-derived ranges between the source ship and the MOMAX buoys are shown in Fig. 5, while the ranges between the source ship and the VLA are shown in Fig. 6.

Before providing examples of acoustic data, it is important to point out two important engineering improvements that were made to the MOMAX buoys in 2006, namely the addition of an internal

recording system and a second hydrophone to each buoy. The design depths for the hydrophones are 40 and 43 m. In conjunction with these developments, the telemetry system was modified so that approximately 3-second snippets of acoustic data, each with a GPS position, were transmitted back to the source ship, thereby enabling real-time monitoring of the buoy positions as well as acoustic data quality. Examples of 50 Hz data obtained on each hydrophone on all 4 buoys are shown in Figs. 7 and 8, respectively, while the corresponding 125 Hz data are shown in Figs. 9 and 10. There are some interesting features apparent in these data:

- (1) There appear to be correlations between fluctuations in the temperature data and variations in the acoustic data, for example, on day 247.1 at 25 m depth in the Tpod data (cf. Fig. 4) and day 247.06 in the 50 Hz acoustic data (cf. Figs. 7 and 8). These relationships and other correlations of this type are being vigorously pursued in the context of the extensive suite of physical oceanographic data that are available from SW06.
- (2) In some cases, the acoustic data obtained on the upper hydrophone are more variable than the data obtained on the lower hydrophone. These results are consistent with the fact that the upper hydrophone depth (40 m – Channel 1) corresponds to a more dynamic portion of the water column than the lower hydrophone depth (43 m – Channel 2), as shown in Fig. 4. The dependence of this effect on buoy location and frequency is currently being examined.
- (3) Maximum signal levels on Moe, Larry, and Shemp occur at times (approximately day 247.43) corresponding to the point of closest approach between the source and the buoys (cf. Figs. 5 and 7-10). These and other geometrical effects on low-frequency propagation are under current investigation.

In addition, the mainstream processing of these data (described in the Work Completed section) has begun, namely the merging of the pressure magnitude and phase data with the corresponding GPS-derived source-receiver ranges versus time. The resulting pressure magnitude and phase versus two-dimensional position data will be beam-formed and used in geoacoustic inversion algorithms. These data will also be used to estimate the influence of water column variability on geoacoustic inversion.

Finally, the Webb VLA acoustic data look very promising, and efforts to process the signals obtained both from the J15-3 source, as well as the other sound sources in the area have begun.

## **IMPACT/APPLICATIONS**

The experimental configuration consisting of a CW source and freely drifting buoys will provide a simple way to characterize a shallow water area and may be useful in survey operations. In addition, the planar, synthetic receiving array may offer an effective new technique for localizing and tracking sources of unknown, quasi-stable frequency in shallow water.

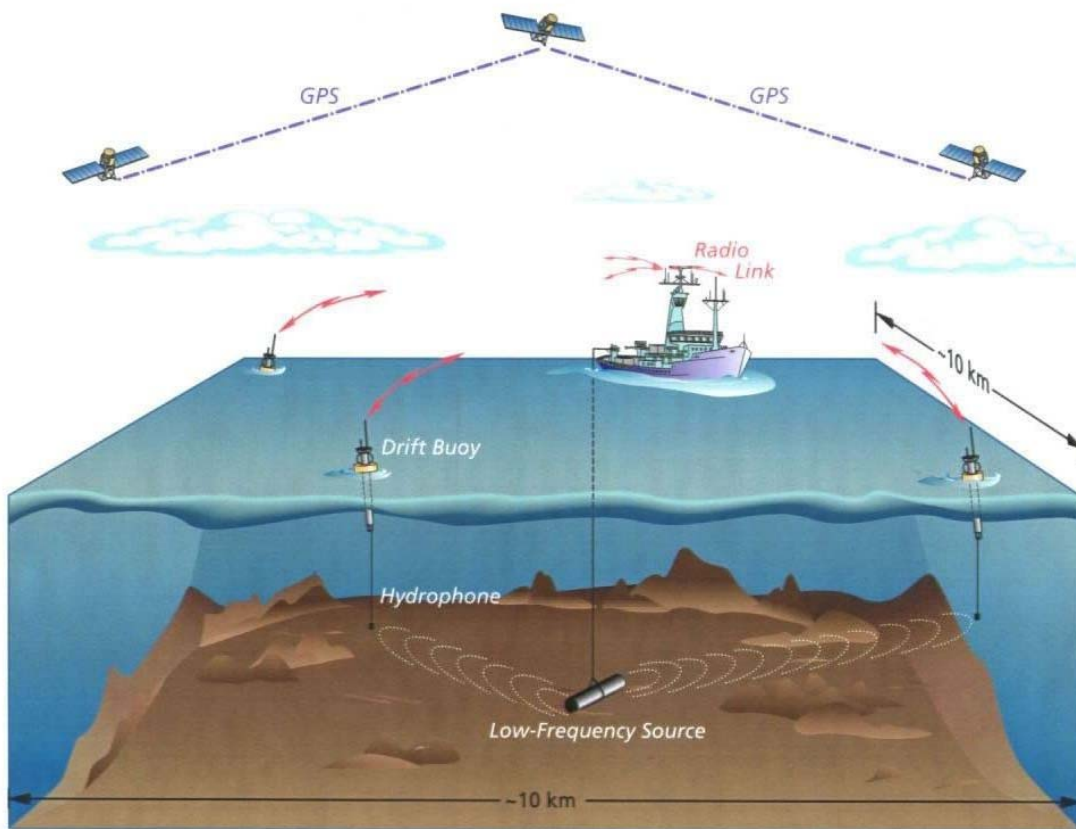
## **TRANSITIONS**

The synthetic aperture technique and Hankel transform inversion methodology which underlie the modal mapping method have been implemented in the ACT II experiment, sponsored by DARPA and ONR, and have been used in the REMUS towed array experiments being conducted by Carey and Lynch. This approach has also been adopted by several research groups internationally, including the Japanese groups involved in SWAT.

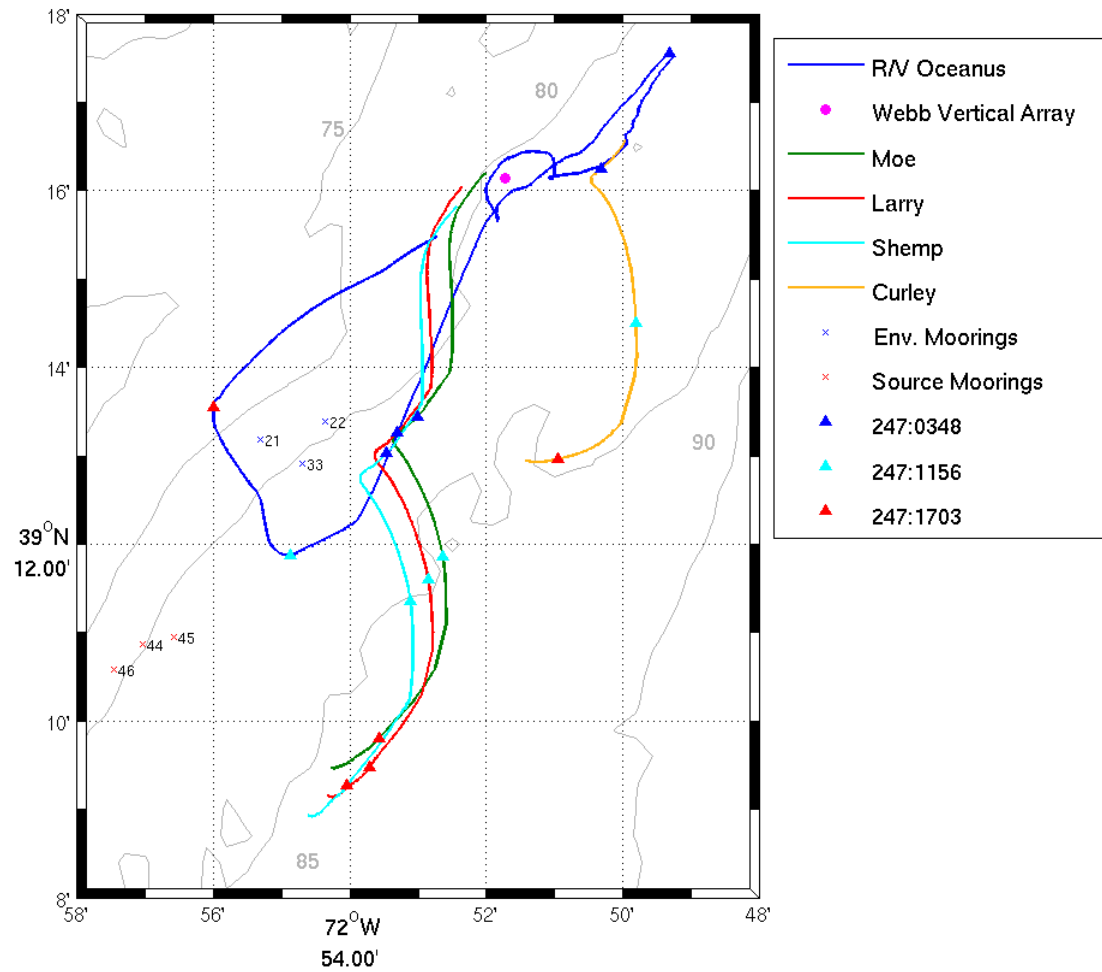
## RELATED PROJECTS

MOMAX I and III were conducted in the same area off the New Jersey coast where the ONR-sponsored STRATAFORM, SWARM, PRIMER, Geoclutter, and Boundary Characterization experiments were carried out. The extensive geophysical, seismic, acoustic, and oceanographic data obtained in these experiments are being used to ground truth the MOMAX measurements.

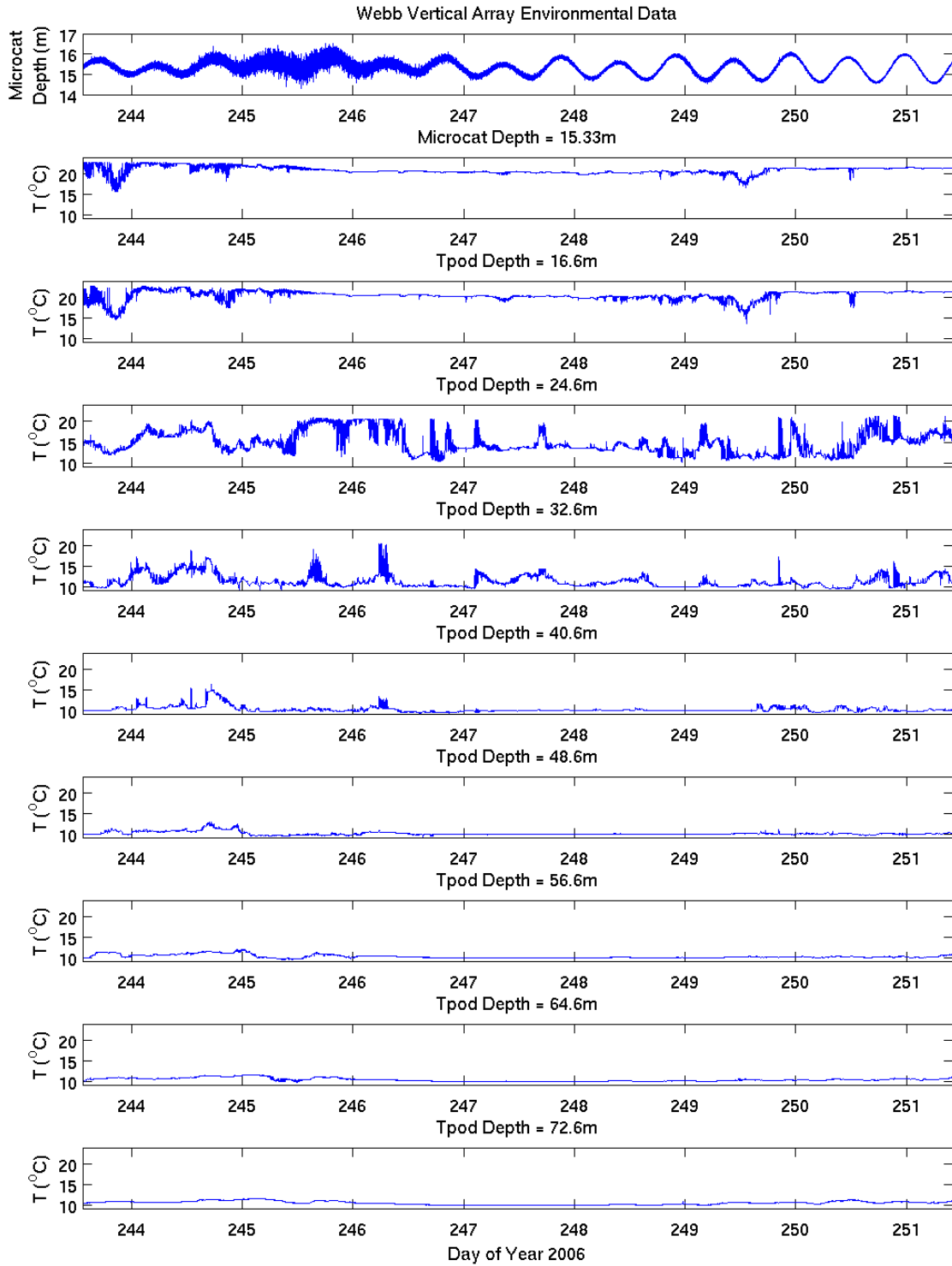
The LWAD 99-1 Project included a broad range of underwater acoustic and environmental measurements, in addition to MOMAX II. The results from these other experiments are being used to assist in the interpretation of the MOMAX II data.



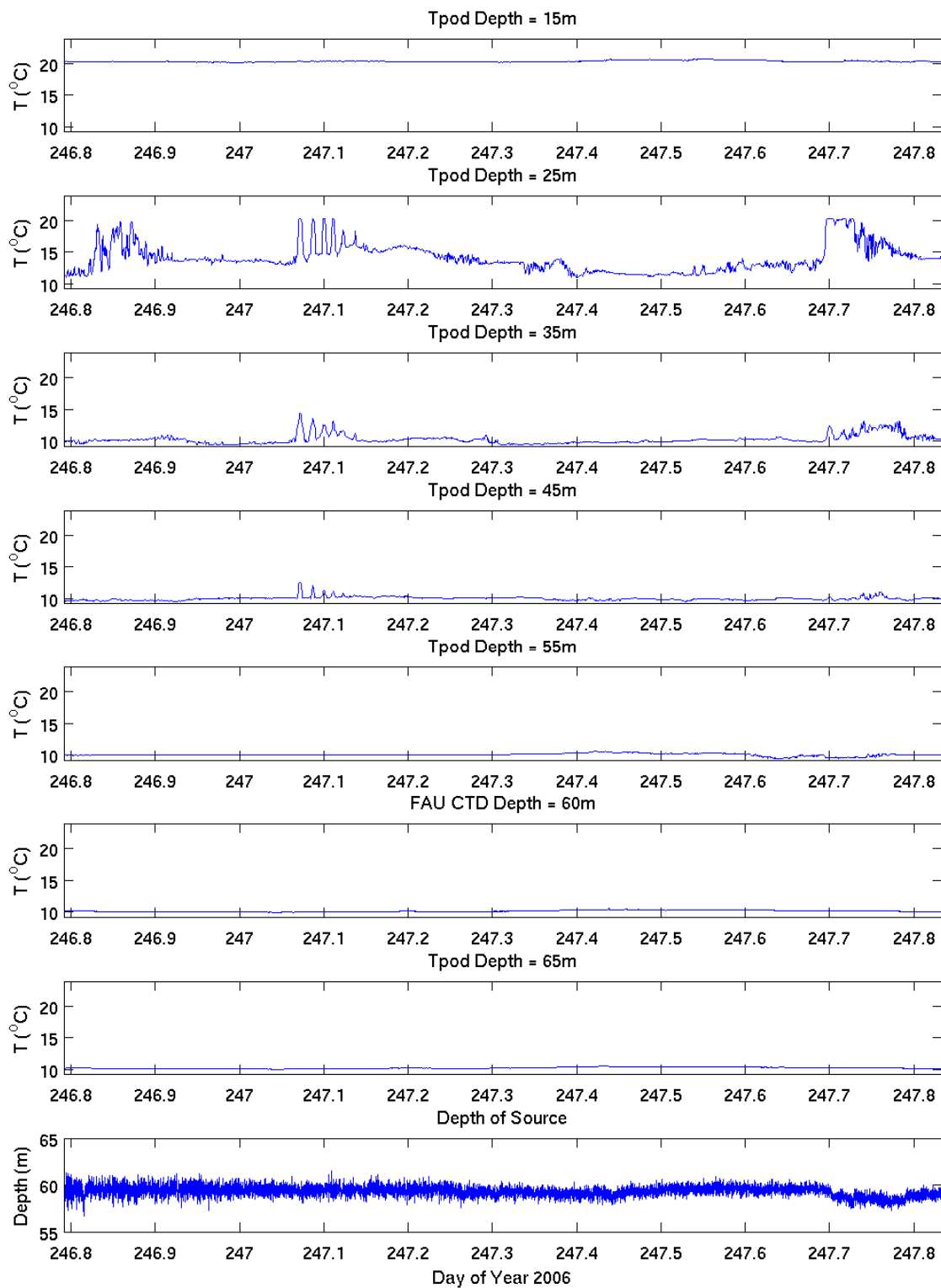
*Figure 1: MOMAX experimental configuration.*



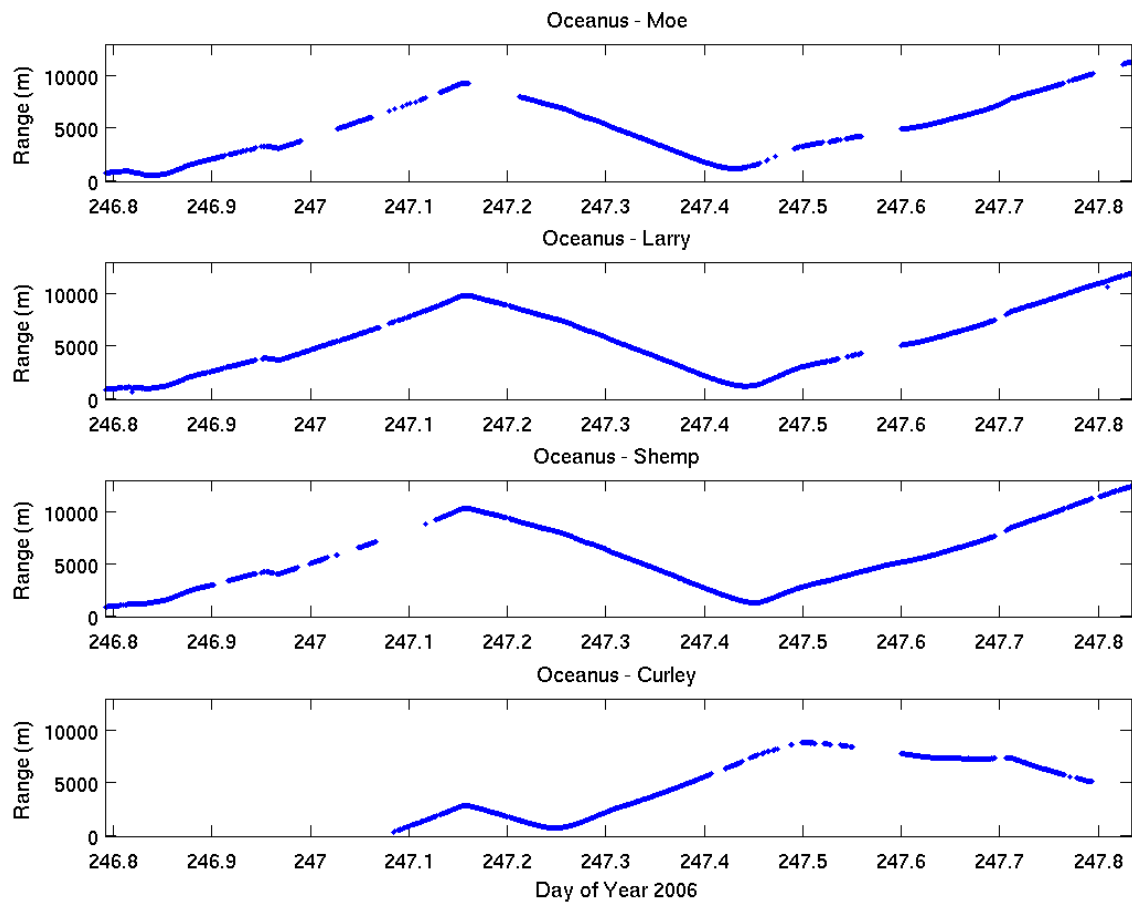
**Figure 2: Tracks of source ship (R/V Oceanus) and 4 drifting buoys (Moe, Larry, Shemp, Curley) for the SW06/MOMAX IV Experiment. Also shown are the Webb VLA, 3 environmental, and 3 source moorings in the experimental area.**



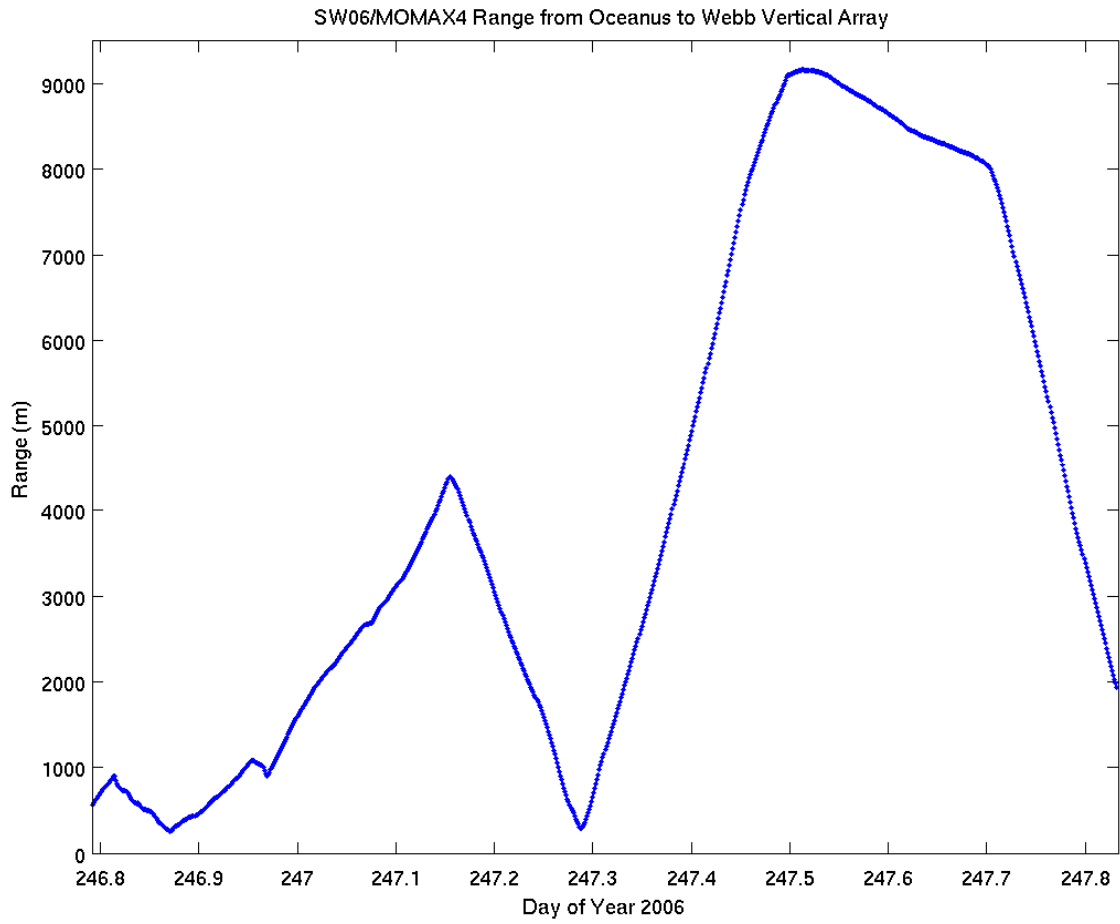
*Figure 3: Temperature versus depth measurements obtained on the Webb VLA.*



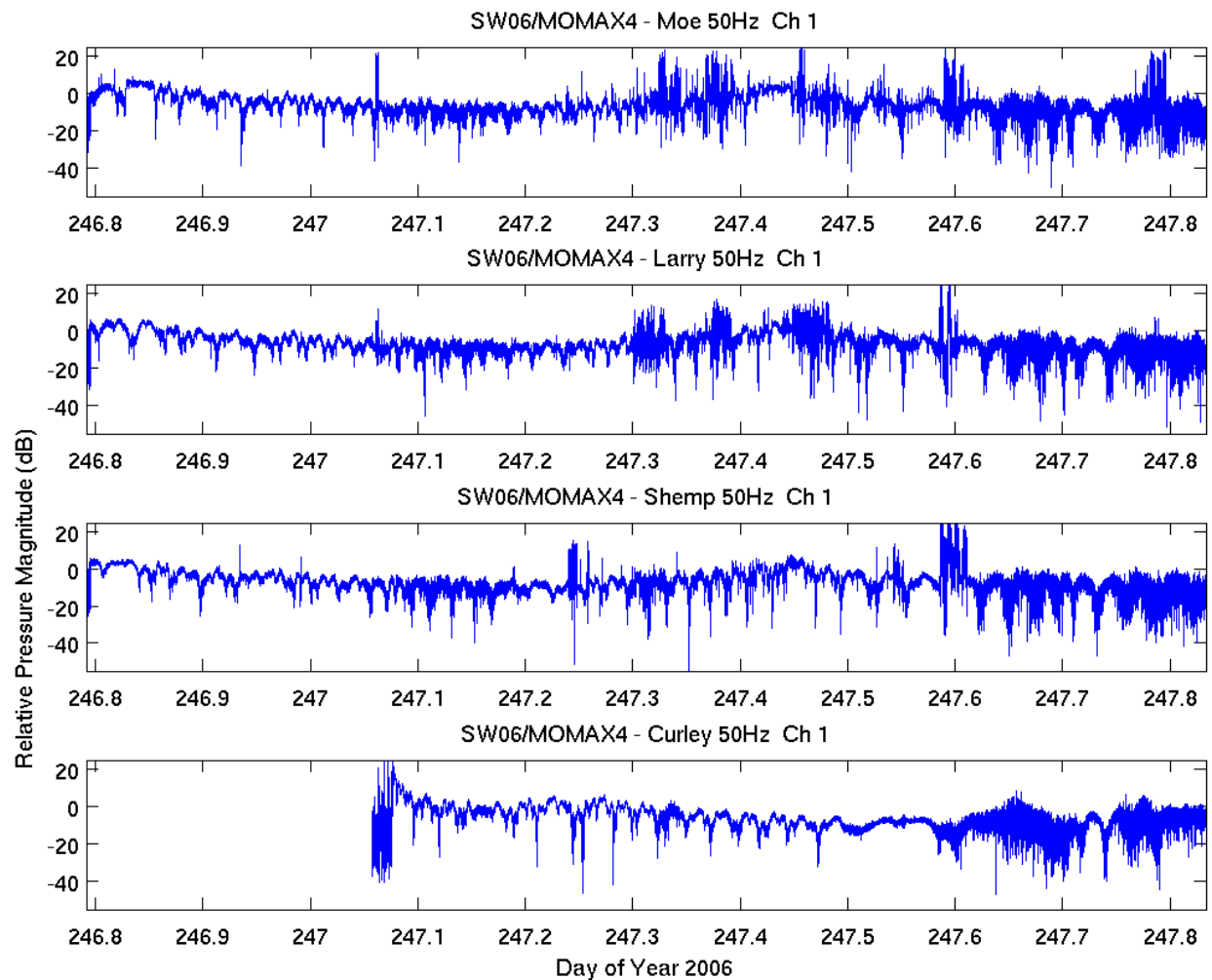
**Figure 4: Temperature versus depth measurements obtained on the NUWC J15-3 source string. Also shown is the source depth measured by the FAU CTD.**



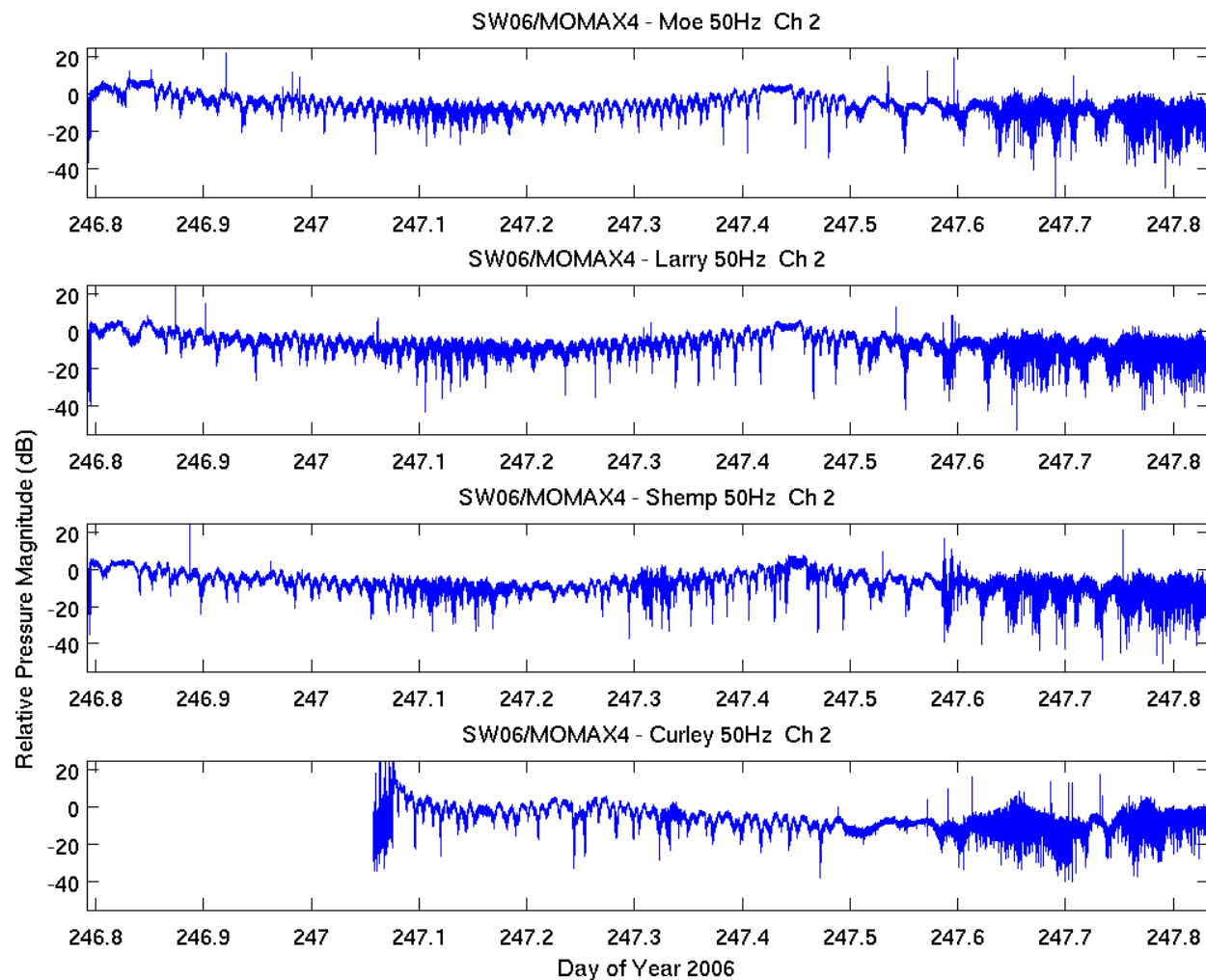
**Figure 5: GPS-derived ranges between the source ship and the 4 MOMAX buoys.**



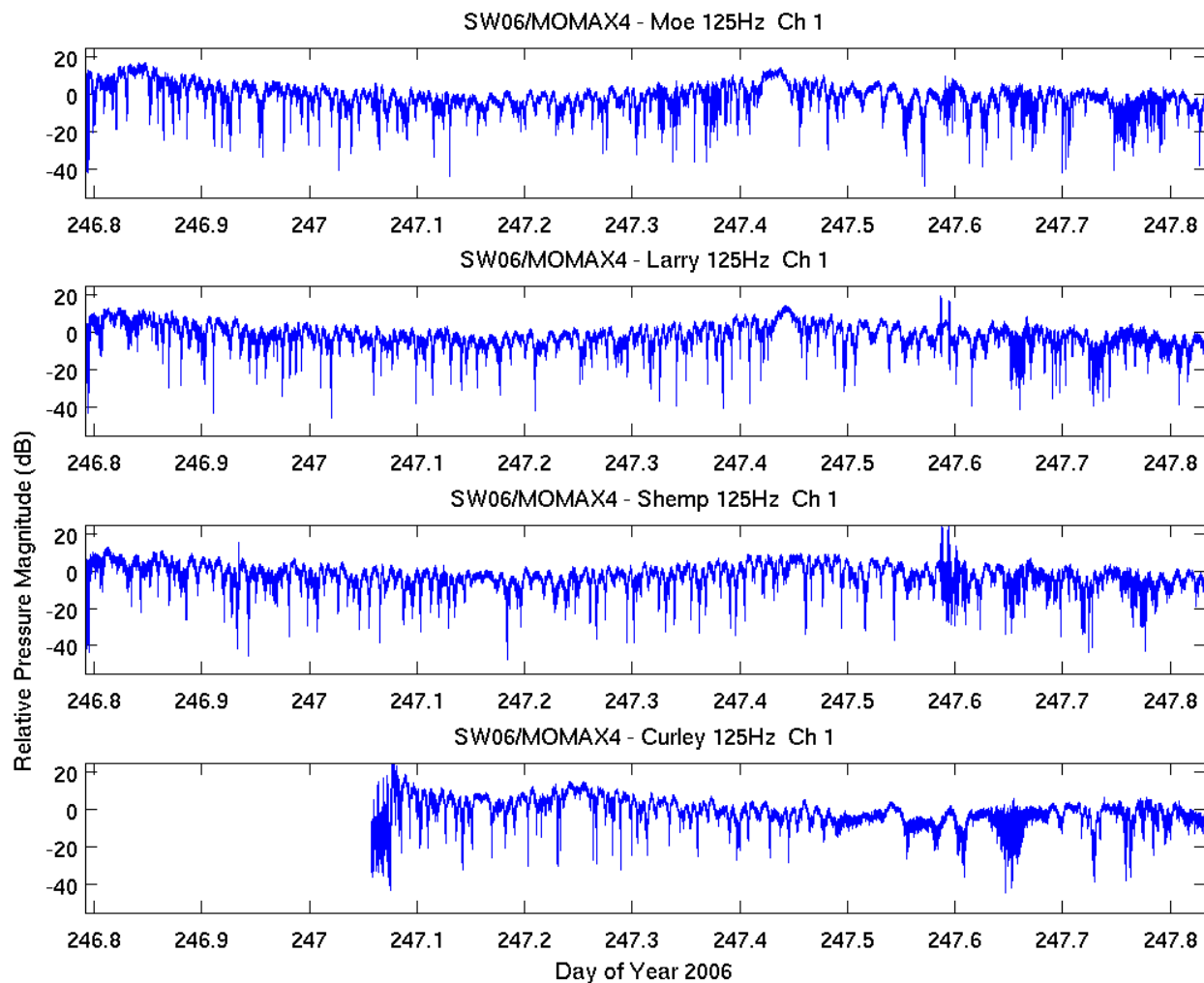
***Figure 6: GPS-derived ranges between the source ship and the Webb VLA.***



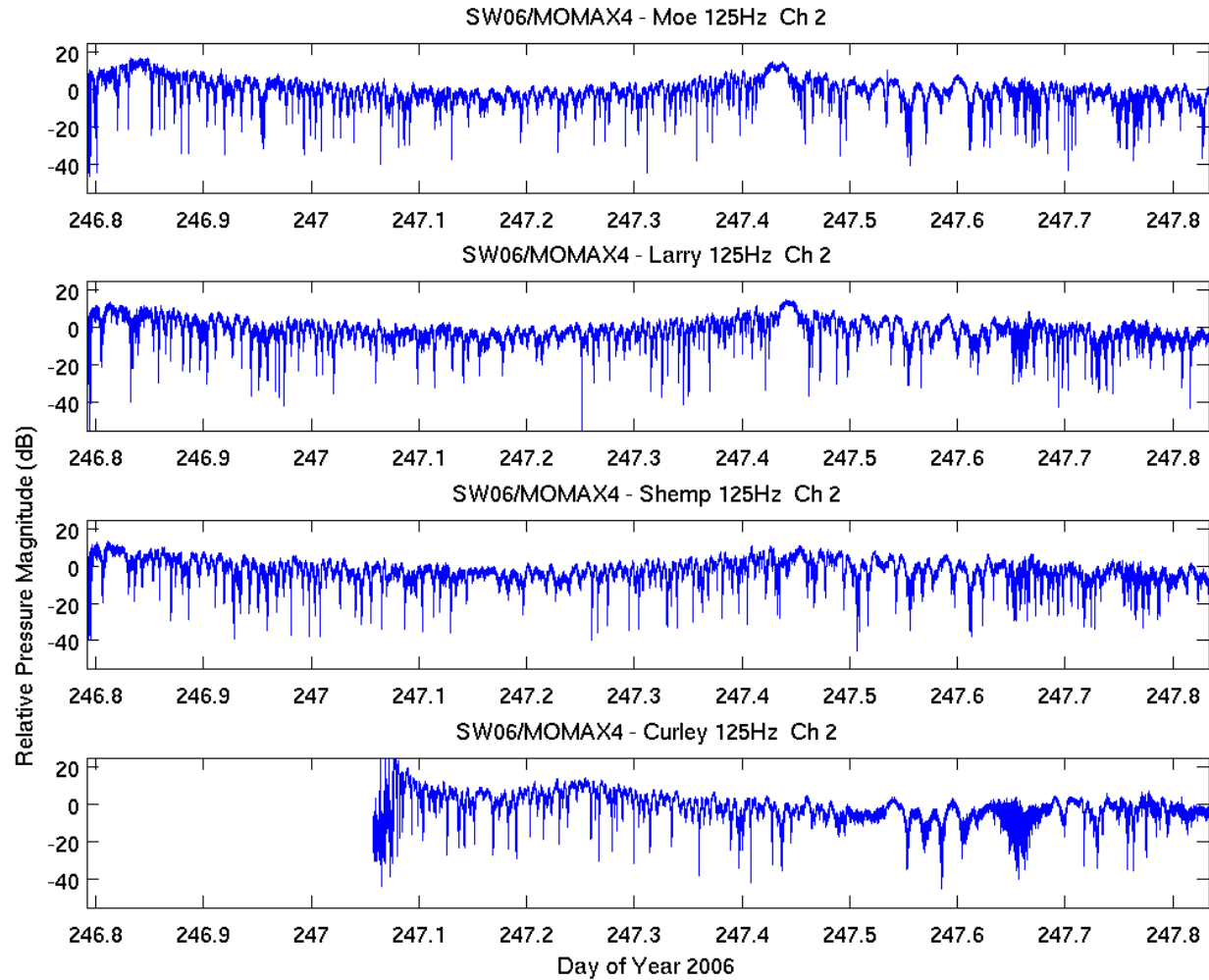
*Figure 7: Relative pressure magnitude at 50 Hz measured on the upper hydrophone for the 4 MOMAX buoys.*



*Figure 8: Relative pressure magnitude at 50 Hz measured on the lower hydrophone for the 4 MOMAX buoys.*



*Figure 9: Relative pressure magnitude at 125 Hz measured on the upper hydrophone for the 4 MOMAX buoys.*



**Figure 10: Relative pressure magnitude at 125 Hz measured on the lower hydrophone for the 4 MOMAX buoys.**

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## **HONORS/AWARDS/PRIZES**

G.V. Frisk, Vice President-Elect of the Acoustical Society of America (May 2006).